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COMPLETE SPECIFICATION

Selector Switching Systems Utilising Optical Interconnecting Paths Occupying a Common Space

I, SPIRO JOHN CATRAVAS, of 19 Cranwell Avenue, Strathmore, W.6, a suburb of the City of Melbourne, in the State of Victoria, Commonwealth of Australia, a British Subject, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to improvements in selector switching system techniques where it is required to effect separate inter-connections between selectable pairs (or more if required) of terminating circuits, among a plurality of terminating circuits, many such separate inter-connections being possible to exist at any one time or interval thereof and the combinations being in strict conformity with the prevailing demand.

Selector switching systems employ a multiplicity of "switching elements" or "cross-points," arranged in some systematic manner so as to fulfil the required functions.

Switching elements are two-state controllable devices, serving to inter-connect in one state and disconnect in the other the circuits at their terminals.

It is necessary at this stage, for the purpose of clearly expressing the nature of this invention, to define some terms associated with switching elements. A switching element comprises a "connecting section" and a "controlling section" to operate the connecting section as required. The connecting section comprises, in a basic form, two contacts, if it is metallic in nature, or electrodes, if it is electronic in nature, which shall be referred to hereafter in this specification as "poles," each of which leads to different terminals for attachment to the external circuits. An inter-connecting path is established between the poles only in the "make" state allowing the flow therethrough of intelligence or information between the terminating circuits. In the "break" state the inter-connecting path is broken and the poles are mutually isolated. The means responsible for the establishment of an inter-connecting path between the poles is hereafter referred to as the "linking medium." The linking medium is under the control of the controlling section serving to "make" or "break" a connection by making contact with or establishing an inter-connecting path between the poles. With metallic connecting sections the linking medium is either a separate metallic element or forms an integral part with one pole so that in the "make" state only one contact is actually made between the poles. With electronic switching elements the inter-connecting path is established through the linking medium, which is an electronic or other charged particle flow, in space or solid, between the electrodes serving as poles (viz. electron valves or semiconductor devices).

From the point of view of traffic handling performance, it is known that there is no better alternative to providing access between every link circuit and every terminating line and further, that large groups of switching circuits carry more traffic than small groups, which latter to the limit would involve one large single group for all the terminating lines to the system. It is economically prohibitive and technically most complex to provide for these ideal traffic requirements in switching systems incorporating existing techniques, because of the enormous number of switching elements that would be necessary.

Nevertheless, the above ideal traffic requirements and other advantages would be obtained if a switching system were realised analogous to a hyothetical automatic double-cord switching arrangement without multiples and preferably involving a single switching stage, in which each of the terminations makes but a single appearance analogous to one outlet or jack per terminating line) the interconnections between the terminations being effected by a relatively small but traffic-wise adequate number of common link circuits (analogous to cord circuits) extending positionable linking media to meet the terminations requiring interconnection.

One main object of this invention is the utilisation of optical and opto-electric techniques enabling the technically feasible construction of opto-electric selector switching arrangements, hitherto only crude and technically impractible propositions, in which directable narrow optical beans, of LASER origin or otherwise obtainable through special narrow beam-forming process, emanating from and positionable by common linking units (functionally analogous to automatic cord circuits), serve as linking media to interconect intelligence-carrying circuits in the fields where selection may be required such as telephony, computers, telegraphy and others, because of the advantageous features specially available in the optical domain which may be exploited in combination with others and particularly the electronic domain, so as to expand the scope and secure many improvements and economies that have not been possible in prior art of electro-mechanical or purely electronic selective switching systems.

Another main object of this invention, because of the advantageous features available in the optical domain, is the joint utilisation of optical and opto-electronic techniques in time-division multiplex selector switching arrangements, in which time-shared optical beams emanating from and positionable by fast operating opto-electronic common linking units, serve as time-shared optical linking media which, in conjunction with other electronic switching elements, serve to interconnect intelligence carrying circuits with an unprecedented traffic-handling ability while eliminating certain objectionable complication and limitations encountered in hitherto time-division-multplex switching systems utilising purely electronic means.

An object of the invention in using directable or positionable optical beams of any preferred type of light without limitation (whether it be visible, invisible, white, monochromatic incoherent or coherent) as "linking media" between opto-electric transducer "poles" to effect selected interconnections among or between the terminating circuits, is due to the advantages offered by the natural properties of optical beams in relation to the desirable linking media requirements as regards length of reach, unsaturable and unlimited crowding in a common space, absence of mutual physical obstruction allowing obstruction-free movement and interpenetration along mutually overlapping sections or at intersections, absence of interaction regarding directionable deviation due to mutual proximity or intersection and freedom from interference after the separation of two or more beams beyond an overlapping section due to an intersection thereof, said advantages enabling the utilisation of a common space in which an unlimited multiplicity of separate interconnecting paths for continuous or time-multiplexed transmission may coexist uninterferingly (cords in a manual telephone) switchboard being to a very limited extent analogous to the above) which arrangement is not realisable in any electro-mechanical or purely electronic switching systems where, on the contrary, for lack of equivalent properties without the optical domain the interconnecting paths, unless time-shared, must be kept individually separated in space (space-separation or space-division sytems).

An object of the invention in utilising a common space in which an unlimited multiplicity of separate optical interconnecting paths may coexist uninterferingly, is that it is possible to realise only a single terminal appearance, with the associated opto-electric transducer means, per terminating external circuit, as against existing electro-mechanical or purely electronic automatic switching systems utilising space-separated interconnecting paths which necessitate a plurality of switching elements associated with the repeated terminal appearance forming into multiples.

Another object of the invention in utilising a common space in which an unlimited multiplicity of separate optical interconecting paths may coexist uninterferingly, whereby a common space switching system with a single terminal appearance per external circuit may be realised, is the possible application of the present invention in the field of telephone switching to advantageously effect direct interconnections via common equipment between the terminating lines and/or junctions in a switching system comprising only a single stage, so as to eliminate the complexity of line-concentrators and other multi-stage switching and trunking arrangements encountered in existing telephone switching systems.

A further object pertaining to the application of the invention in the telephone field is that it is feasible to provide a single-stage switching arrangement in which separate groupings of terminating circuits are avoided, access being provided instead between every common linking unit and every terminating line without any restrictions as to the traffic distribution within said switching arangement,

the absolute maximum number of simultaneous calls being limited only by the number of common linking units available in the system regardless of the internal distribution of said calls, or a system in which traffic and trunking complexities and problems are considerably simplified.

A further object pertaining to the application of the invention in the telephone field as outlined in the preceding paragraph is that it is possible, through the provision of an adequate number of common linking units and/or by time-sharing them in a time-division-multiplex optical beam switching system, to realise an essentially non-blocking switching system, i.e. a system having an unrestricted traffic handling capacity there will be suggested a variety of means and methods for positioning the optical beams as required to effect selection between the terminating circuits, some of which are more suitable than other in different applications of the invention.

There will also be suggested means and methods whereby optical beams may be supplied or provided for use according to preference in various applications of the invention.

Also, there will be suggested wide angle retrodirective reflector facilities for use in certain preferred embodiments of the invention.

There will also be suggested means for use in certain preferred embodiments of the invention, whereby it is possible to separate information contained by two superimposed optical beams proceeding in the same direction.

The present invention consists in an opto-electric selector switching system comprising common opto-electric equipment and a plurality of fixed light-sourceless opto-opto-electric elements, in which said switching system interconnecting paths are established between the external network outlets through the intermediary of positionable narrow optical (light) beams linking said opto-electric common equipment to the selected opto-electric terminating units, said optical beams originating only from said common equipment, said common equipment including optical beam orignating equipment and further including optical beam positioning units to direct each optical beam to any seletced terminating unit.

The reason for the adoption of the optical domain in selector switching systems is that this domain and offers facilities permitting the utilisation of a common-space within which the linking media may function and establish individual interconnections between poles of opposite kind, said interconnections existing simultaneously during any interval or instant of time free from mutual obstruction and functional interference, consequently said poles need only be provided or appear once per respective terminating circuit. Such an arrangement is not possible in existing electro-mechanical or purely electronic space-division (or space-separation) systems, where the compulsory provision of space separated interconnecting paths for the various selection combinations involves a separate switching element at any instant for each said path comprising discrete poles confined to and exclusively linkable by the linking medium between their space, as a consequence of which, unless the paths are time-shared, numerous switching elements are required for the paths leading to or from each terminating circuit, the numerous appearances of the associated poles forming a common multiple.

According to suitability in a particular application of the invention, electro-optical modulation may be effected either by any electro-optical transducer externally modulating an optical beam incident thereon from a separate light-source, or by using any internally modulatable source of light, as for example, an intensity modulated cathode ray tube, a gas-filled glow discharge device, a semi-conductor light source, an electro-luminescent device or any other light source in which the light intensity may be caused to vary as a function of an electrical signal applied thereto.

According to the invention, beam positioning may be effected by any means involving the relative displacement between any preferred "light-ray grouping" and "optical elements," the latter term implying such devices as for example mirrors, prisms, optical holes, reflective or refractive types of focusing devices including concave, convex and cylindrical mirrors or lenses etc., though not restricted to "light-ray grouping" implying parallel or slightly diverging rays in beam formation due to any origin without restriction including LASER beams, rays radiating from a light source of any kind such as incandescent, gaseous ionisation glow or discharge, electro-luminescent, stimulated emission of radiation etc., rays from glowing luminous, phosphorescent, fluorescent surfaces or screens, rays from wholly or partly reflecting surfaces, rays from effective or transmissive types of diffusing surfaces or screens, focused ray diverging from or converging to a real or visual image, said sources, surfaces, screen and images being of any shape or size. The said relative displacement between any "light-ray grouping" and "optical elements" may be effected by electronic, opto-electric, electro-mechanical or any other suitable means without limitation. The said electro-mechanical means imply any electrically controlled or operated device, arrangement or mechanism whereby mechanical displacement, twisting, bending, flexing or deformation results directly or indirectly due to the actuating forces therein, said actuating forces being for example electro-magnetic (including moving-coil, eddy-current, etc.) mag-

netic, pneumatic, hydraulic, spring, gravitational, frictional, piezo-electric, magnetostrictive, etc., or combinations thereof.

Various electronic and electro-mechanical mechanisms suitable for different applications of the invention are suggested and/or described further on in this specification with reference to appropriate drawings which form part of this application. Among them is included an electro-mechanical beam positioning mechanism involving magnetic actuating forces which may be established or stored at a fast rate in high magnetic retentivity elements serving to move and place the optical element to various pre-defined positions, and another involving vibrations or small return excursions at different to and fro rates, of the supports or bearings carying the movable optical element which latter may move in any required direction in small steps, by virtue of its inertial response to the said different excursion rates of the supports in conjunction with the mutual frictional forces between them which latter may also, if preferred be made to vary in synchronism with the said excursions of the supports to improve the performance of the mechanism.

According to preference in certain applications of the invention and with certain devices, it is possible to provide integrated arrangements including beam positioning means and light source which latter may be modulatable.

Means are provided to ensure accurate positioning of the optical beams, said means, depending upon the nature of the adopted beam positioning arrangement, may either include some suitable closed-loop opto-electric (feedback) control system to effect corrections as may be necessary, or some digital-analog system, as described further on in this specification with reference to appropriate drawings, such that the required beam positions are defined on a digital basis (preferably involving a parallel binary command) which may be operated directly (on open-loop) if the system by nature retains its calibration permanently, otherwise if by nature the system is subject to slow drift, it may be frequently and automatically recalibrated, against some suitable optical or other reference position at regular intervals preferably time-shared over all of a number of beam positioning units provided in the selector switching system.

Optical means may be provided for use in electro-mechanical beam positioning arrangements employing movable focusing devices, said optical means comprising an additional focusing device fixed on the image locus following a preceding movable focusing device, as described further on in this specification with reference to appropriate drawings, in order to bend towards the main axis of the system that the rays diverging from any displaced image point without affecting its position so that said rays may be intercepted by the following focusing device over a much wider displacement range of the said image point than otherwise possible, resulting both in a wide-angle puerformance system as well as in a substantial reduction in the size and therefore mass of said following focusing device to speed up its movement, reduce wear and minimise the size of the associated mechanism.

Alternative means may be to obtain the results stated in the preceding paragraph without the use of the said additional focusing device are described further on, as they may be suitable for certain applications of this invention, said latter means comprising the use of two cylindrical focusing devices mutually at right angles and in close proximity so that most of the deflected rays emerging from the first cylindrical device may be intercepted by the second cylindrical device, either or both of said devices being movable to position an optical beam as required.

Means suitable for preferred applications of the invention and forming part thereof are described further on with reference to appropriate drawings whereby a common optical beam supply may be provided for all the individual beam requirements of the selector switching system.

Alternative embodiments of the invention are described further on with reference to appropriate drawings in which the plurality of terminations share a reduced number of common linking units including optical beam-positioning equipment available on a common pool basis, each said common linking unit being either time-shared for a number of simultaneous interconnections or else each said common linking unit is assigned for the required duration of the respective individual interconnection in which latter case the assigned common linking unit directs an optical beam emanating therefrom to the relevant sending electro-optical transducer pole, said beam after modulation being returned by means of a wide-angle retrodirective reflector back to the said common linking unit for retransmission to the opposite photo-electric transducer pole.

Means enabling the provision of a wide angle auto-collimator for use in one embodiment of the invention and forming part thereof are described further on in this specification, said means comprising the use of a focusing device fixed on the image locus of an auto-collimator, in lieu of a plane mirror, this arrangement serving as one possible retrodirective reflector.

As the switching system of the present invention in any of its alternative forms, by nature enables only uni-directional transmission of intelligence through the established interconnecting paths, where bi-directional transmission is required (as for example in

telephony), a similar return path is provided, the two paths leading to the terminating circuits via hybrid networks.

Selector switching systems having optical interconnecting paths and techniques or methods to be adopted for their construction according to the present invention will now be described by way of example with reference to Figures 1 to 40 of the accompanying diagrammatic drawings. In these drawings:—

Figures 1 and 2 illustrate alternative selector switching systems having optical interconnecting paths embodying the principles of the present invention.

Figures 3 to 5 illustrate the basic optical principles whereby deflection of optical beams may be obtained.

Figures 6 to 7 illustrate the optical principles involved in two-dimensional deflection of optical beam effected by the displacement of focusing devices along co-ordinate axes.

Figures 8 to 15 illustrate problems associated with the deflection of optical beams and means or methods of correcting same.

Figures 16 and 17 illustrate some electronically operated optical beam positioning arrangements.

Figures 18 to 28 illustrate open-loop and closed-loop electro-mechanically operated optical beam positioning arrangements and details thereof.

Figures 29 and 30 illustrate an optical beam co-ordinate analyser for use with the opto-electric position-servo systems of closed-loop electro-mechanically operated optical beam positioning arrangements.

Figure 31 illustrates an optical beam-dividing distributor arrangement serving to divide a wide common or main beam into a plurality of narrow optical beams.

Figures 32 and 33 illustrate methods of obtaining main beam supplies of good parallelism including fool-proof means whereby an uninterruptable supply is ensured.

Figure 34 illustrates a combined collimating beam-dividing distributor arrangement to supply a plurality of narrow optical beams of good parallelism.

Figure 35 illustrates a beam separating distributor serving to separate a plurality of subsidiary narrow beams off a main narrow LASER beam.

Figures 36 to 38 illustrate wide angle retro-directive auto-collimator facilities for use in the system of Figure 1.

Figures 39 and 40 are details of common-linking units for use in the system of Figure 1.

In carrying the invention into effect according to the forms illustrated by way of example in the drawings, and referring first to Figure 1, the following are provided:—

A plurality of terminating conbined sending-receiving units SRU1, SRU2, SRU3 . . . SRUN. each comprising a wide angle retro-directive reflector, an electro-optical modulating transducer and a photo-electric demodulat-transducer. In addition, a plurality of "common linking units" CLU1, CLU2, . . . CLUK are provided, each with two sections I and II, each said section comprising beam positioning means, so that an optical beam may emanate from section I to meet a selected terminating sending-receiving unit and another optical beam may emanate from section II to meet another selected terminating sending-receiving unit. The said terminating sending-receiving units and said common linking units are mounted in any convenient way which enables the latter units by means of positionable optical beams emanating therefrom, to link the said terminating units optically, the optically interlinkable outlets or optical apertures of both said types of units as well as said positionable optical beams being contained within an optical chamber or darkroom. Figure 1 shows a plan view of one possible arrangement in which the terminating sending-receiving units are mounted on one row or level facing the common linking units, although the invention is not bound to this particular mounting arrangement. Where many more units must be accommodated, the arrangement of Figure 1 may be regarded as representing one of many rows or levels, in which case the terminating units and if necessary the common linking units as well, virtually form banks facing each other, where any terminating unit in any level may be linkable optically by anyone of the common linking units in whatever level the latter may be mounted. If preferred, the terminating units and common linking units may be grouped on the same side facing a mirror, the beams being directed to and reflected by the said mirror to link any common linking unit to the selected pair of terminating units.

Each section, I or II, of a common linking unit is associated with a selected terminating sending-receiving unit by three parallel optical beams, as described further on, which said parallel optical beams may be either close by to one another of superimposed, the former serving more conveniently only for illustrating purposes in Figure 1. The common linking units are not permanently assigned to the terminating sending-receiving units, but are instead intended to serve on a common pool basis, whereby any unoccupied common linking unit may be allotted for any required duration to establish interconnecting paths between any selected pairs of terminating circuits. The quantity of common linking units will depend upon the traffic and grade of service to be offered, usually of the order of ten percent of the number of said terminating units. The optical beams arriving from any common linking unit are modulated through the electro-optical transducers at the sending sections of the selected terminating units by

the information signals applied to the electrical terminals, TS1, TS2, TS3, . . . TSN each leading from a different external circuit, the said optical beams arriving unmodulated from any section of a common linking unit are hereafter referred to as the "original" beams. The original beams upon modulation are reversed back modulated to the originating common linking units by means of the rectro-directive reflectors in the terminating units, originating common linking units to be hereafter referred to as the "incoming" beams, are redirected by the originating common linking units to the opposite terminating units where the intelligence is demodulated by the photo-electric transducers at the receiving stations thereof, the electrical demodulated signals appearing at the terminals TR1, TR2, TR3, . . . TRN. The modulated beams arriving for reception and demodulation at the receiving sections of the terminating units (after being redirected by the originating common linking units) are referred hereafter as the "outgoing" beams.

In operation, with reference to an example in Figure 1, an unmodulated "original" optical beam BLS2 emanating from section I of a common linking unit CLU1, is directed to meet the selected terminating sending-receiving unit SRU2 where upon modulation by the intelligence signals arriving at terminal TS2 by means of the electro-optical transducer (not shown) included in this unit, the modulated beam is reversed back to section I of the common linking unit CLU1 as the "incoming" beam BS2L through the action of the retrodirective reflector (not shown) in the said terminating unit. Through electro-optical or optical redirectional means provided in each common linking unit, the modulated incoming beam BS2L in this example is retransmitted or redirected from section I of common linking unit SLU1 to section II thereof where upon deflection by the positioning means therein it is transmitted as the "outgoing" beam BS2LRN to meet the terminating unit SRUN where the latter said beam is demodulated by the photo-electric transducer (not shown) in the receiving section of the latter terminating unit, the received electrical signals appearing at terminal TRN. Clearly, the incoming and outgoing beams, BS2L and BS2LRN respectively, are derived from the original beam, BLS2, and if the latter is turned off, the others will also disappear as a consequence.

The operation of the system as described with reference to Figure 1 so far involves transmission in one direction only from the sending section of one terminating unit to the receiving section of the opposite terminating unit. In applications where bi-directional communication is required, such as in telephony, a return path may be provded through the same common linking units interconnecting the two terminating units, provided that each terminating unit comprises both sending and receiving sections. Hybrid networks, such as H1, H2, H3,———HN, are provided in bi-directional transmission applications where two-wire instead of four-wire external circuit terminations are required so as to couple the electrical incoming and outgoing terminal pairs to the single terminal pair of the external circuits. Thus in such applications hybrid H1 couples incoming terminal TS1 and outgoing electrical terminal TR1 to the external circuit terminal ECT1 of Figure 1, where schematically each said shown terminal represents a terminal part in the actual circuit. Similarly hybrid H2 couples TS2 and TR2 to ECT2, hybrid H3 couples TS3 and TR3 to ECT3, . . . and hybrid HN couples TSN and TRN to ECTN.

Extending the earlier example with reference to Figure 1 to include bi-directional transmission, a simlar sequence of events takes place for the return path as follows:— From section II of CLU1 (or any other common linking unit) emanates the original unmodulated optical beam BLSN, which after modulation and retrodirective reflection at the terminating sending-receiving unit SRUN, is reversed as the incoming beam BSNL entering section II and re-emerging from section I of the common linking unit CLU1 as the outgoing beam BSNLR2 carrying the intelligence transmitted by the unit SRUN to the unit SRU2. In the latter unit after photo-electric demodulation, the intelligence is transmitted electrically to the there terminating circuit. Many other beams may simultaneously exist between other terminating units without mutually interfering or obstructing one another no matter what the selected combination pairs are, the maximum number of possible interconnected pairs of terminating units being equal to the number of common linking units provided within the system, quite independently of traffic distribution therein, as the terminatng units are not arranged in any separate groupings, whereby any interconnection is possible so long as an idle common linking unit is available anywhere in the system. This affords the possibility of easily correcting any deterioration in the grade of service caused by increased traffic, through the insertion of additional common linking units.

The operation of the optical beam positioning equipment within the common linking units is directed by a centralized control unit (shown in the diagram) through the CLU-CONTROL cables.

In bi-directional system as described with reference to Figure 1 it is convenient to visualise each terminating unit with its sending and receiving sections as a complex "pole" assembly having two conjugate sections namely a "go" and a "return" section.

The advantage of the present system over any other space-division system is obvious in that each pole makes but a single appearance and can be associated with anyone of a plurality of other poles without multipling.

For the purpose of obtaining a clearer understanding, the system described with reference to Figure 1, may be compared with a double-cord telephone switchboard in which the jacks make but a single appearance on a huge switchboard, and where all jacks are within reach of the operator. The terminating sending-receiving units may be considered as analogous to the jacks and the common linking units with the associated optical beams as analogous to the cord circuits, which latter need only be sufficient to cope adequately with the traffic demands, and which may be easily increased if traffic demands increase.

It is necessary that means be provided so that the original beam's light does not mask the light from the intelligence carrying outgoing beam intercepted by any photo-electric transducer. Various principles may be adopted for the latter, some of which will be described elsewhere in this specification.

With applications in the field of telephone switching additional registering equipment will be required to store the dialled information. A convenient arrangement will be for the next free register to be seized by the next available common linking unit in preparation for a future interconnection. Upon initiation of a call section I of the common linking unit will position the original beam to meet the calling terminating sending-receiving unit. The dialled information may be received through the incoming beam modulated by the dial impulses and the information received by the common linking unit may be passed on to the register either optically or electrically, photo-electric transducer facilities being available in the common linking units in the latter case. Upon receiving sufficient information, the register through the common control unit may mark the called terminating called line, in the case of a junction-call, or after receiving the full dialled information, may likewise mark the called subscriber's line in the case of a local call. Thereafter, section II of the common linking unit will be controlled by the centralized control unit to position the original beam therefrom to the marked terminating sending-receiving unit associated with the called line. The interconnecting path from calling to called subscriber or junction is established as described earlier with reference to Figure 1. Amplification may be inserted, if required, anywhere in the system either in the terminating sending-receiving units prior to modulation or after demodulation and/or within the common linking units themselves, through opto-electrical amplifying means supplying an outgoing beam of higher modulated power than that in the incoming beam. Tone signals and inter-exchange signals, in the case of junction-calls, may be transmitted by modulating the original beam from within the common linking units upon instruction from the associated registers. Suitable means capable of handling the ringing signals to the called subscriber's bell must be additionally provided.

It is possible to effect further reduction in the common linking units and the associated beam-positioning equipment by adopting time-division multiplexing so as to time-share the common linking equipment. In such a case the positioning equipment must operate fast and consequently the positioning means must be electronic in nature.

Referring to Figure 2, the following is provided in a time-division multiplexed switching system utilising optical interconnecting paths:—

A plurality of group highways, GH1, GH2, . . . GHJ, J in number, each said highway being electrically associated with a time-shared common linking unit comprising a time-shared sending and positioning section as well as a suitable number of terminating circuits (say about 50) via individual gates, thus for example group highway GH1 is electrically associated with common linking unit CLU1t including the time-shared sending section SU1t and time-shared beam positioning unit PU1t, the terminating circuits to the latter group highway being TS11, TS12, TS13, . . . TS1M via their respective "and" gates, and so on for the other group highways. A plurality of photo-electric receiving units equal to the total number of the terminating circuits associated with all the highways, is also provided in this system, such as the columns of receiving units RU11, . . . RU21, . . . up to RUJ1, . . .

The interconnecting path between any selected pair of terminating circuits is time-division multiplexed in the electrical domain from the termination through the associated "and" gate and group highway up to the electro-optical transducer in the time-shared common linking unit associated with the said group highway, and in the optical domain from the time-shared common linking unit associated with the said group highway to the photo-electric transducer in the receiving units associated with the opposite terminating circuit.

Conveniently an integrated electro-optical transducer and beam positioning means may be an intensity modulated cathode ray tube. Synchronous pulses are applied to the "and" gates associated with all of the J terminating circuits in the same row, so that one gate per highway is opened during any one pulse, via the row pulsing leads, PL1, PL2, PL3, . . . PLM, whereby a total of J interconnecting optical paths may exist, one from each high-

way through the associated time-shared common linking unit at any said pulse, linking the respective receiving units. This in effect amounts to having a total of J synchronous in-phase but electrically space-separated channels existing simultaneously during the same pulse interval. Sequentially other phase-shifted pulses are applied in accordance with a modified time-multiplexed arrangement, to the other rows in successive order, until all the terminating circuits in each highway have been scanned, the process repeatedly being continued thereafter. During each pulse a different position is assumed by each beam associated with each group highway. The total number of space-separated time-division channels being equal to the number of pulses per period times the number of highways (or $M \times J$) and this of course equals the total number of terminating circuits in this system. Consequently, this system has an unrestricted traffic handling capacity, or is a "non-blocking" switching system. As the transmission is unidirectional from any of the TS variety of terminals to any selected photo-electric receiving unit and its corresponding TR terminal, in applications requiring bi-directional communication, such as in telephony, each external circuit will need to be electrically associated with a TS and a TR type of terminal, for example TS11 with TR11, TS21 with TR21, . . . TSJ1 with TRJ1, . . . Thus if for instance an external circuit (not shown) electrically associated with terminals TS12 and TR12 (not shown) were to be bi-directionally interconnected with another external circuit (not shown) associated with terminals TSJ1 and TRJ1, one direction of the transmission would be effected from TS12 to TRJ1 when the pulses to the second row of all the highways are applied and the positioning section associated with the GH1 group highway, namely PU1t, positions the beam modulated by the signal from TS12 to the receiving unit RUJ1. The other direction of transmission would be effected when the pulse 1 is applied enabling transmission from TSJ1 via the group highway GHJ and the positioning section PUJ1 to the receiving unit RU12 and the thereto termination TR12 (not visible). Hybrid networks will need to be provided where two-wire external circuit terminations are required, between the TS and TR terminals in a similar way to that described with reference to Figure 1.

The pulses such as PULSE-1, PULSE-2, PULSE-3 . . . PULSE-M, may be applied to the gates through the associated pulse-leads from a PULSE SUPPLY (shown in Figure 2,) conveniently through a pulse distributor included in the said PULSE SUPPLY. Time for beam positioning must be allowed before the opening of the gates by the gate pulses and this may be effected by allowing sufficient interpulse interval as a position control interval such as PCI-1, PCI-2, PCI-3, . . . PCI-M. The optical units of the switching system are housed in an optical chamber or dark-room.

It should be understood that the invention is not limited to the above described manner of sequentially pulsing the "and" gates of each highway in a successive order.

Figures 3 to 5 serve to illustrate the fundamental principles of optical beam deflection upon which are based the beam positioning arrangements or means to be further described with reference to Figures 6 to 28, which are suitable for use according to suitability in the earlier described selector switching systems of Figures 1 and 2. In the fundamental principles the resulting beam deflection is linearly related to the relative displacement between the "light ray grouping" and the associated "optical elements" (the latter term being as defined earlier in this specification).

Referring first to Figure 3, a focusing device D, fixed in space, is provided meeting light rays from a point-of-ray-divergence situated on the focal plane or surface F of the said focusing device. The point-of-ray-divergence may be either a physical light source of small dimension, or due to a minute optical hole or minute mirror intercepting rays from a broader light source or a diffusing surface, or else may be a bright image point of meeting rays caused by some preceding focusing means (not shown).

With the point-of-ray-divergence situated at O, the focusing device D collimates the rays from O into an optical beam in the direction B, the latter illuminating the spot P on a distant screen Q. The beam direction being always parallel to a straight line from the point-of-ray-divergence projected through the centre of optical symmetry of the focusing device, so if the point-of-ray-divergence is moved by suitable means along the focal plane F to any other point such as Ox, then the collimated beam moves accordingly to the direction Bx illuminating a spot Px on the screen Q. The movement of the illuminated spot is directly proportional to the displacement of the point-of-ray-divergence and equidistant displacements of the latter will result in proportional equidistant positions of the illuminated spot on the screen.

The described principle, illustrated in Figure 3 may be applied to either of the switching arrangements described with reference to Figures 1 or 2, the banks of terminating units taking the place of the screen Q (merely introduced to facilitate the explanation) if it be possible to accurately define the positions of the point-of-ray-divergence in accordance with the distribution pattern of the mounted terminating units.

Referring to Figure 4, an alternative arrangement to that described with reference to

Figure 3, the movable item is the focussing device D as the direction of the optical beam depends upon the relative positions of the focusing device and the point-of-ray-divergence, and therefore it is immaterial as to which item is movable, by suitable means, to effect beam deflection. Figure 4, illustrates two positions, D and Dx of the focusing device and the corresponding beam positions B and Bx.

In applications based on the beam deflection principle illustrated in Figure 3, the displacement of the point-of-ray-divergence may be effected by electronic means or electro-optical means if use is made of certain types of physical light sources lending themselves suitably to the adoption of the above principle, otherwise, electro-mechanical means may be used to obtain mechanical displacement of the optical elements responsible for the formation of either the point-of-ray divergence, as in Figure 3, or of the beam, as in Figure 4, which however implies a comparatively slow response time because of the masses of such elements and the associated mechanisms. With electro-mechanical beam positioning applications it is preferable to resort to arrangements as described further on in this specification, which permit a minimization of the masses of the moving parts in order to reduce the response time and reduce friction and wear.

It is possible to combine the arrangements of Figures 3 and 4 (shown in Figure 6) in applications where access through two independent control paths may be desired, such as for example to position the optical beam through two co-ordinate reference axes.

The focusing device D as shown in Figures 3 and 4 implies a refractive type, namely a lens, but however a reflective type of focusing device, as say a concave mirror, is preferable (shown in Figure 5) because among other advantages it can be constructed to possess less mass, if it is to be movable, as well as being free from chromatic aberration, permitting the use of white light if preferred.

Referring to Figure 5, which is an alternative to either the Figure 3 or Figure 4 arrangements, the concave reflective type focusing device D may be either fixed or movable according to preference, the point-of-ray-divergence being fixed or movable in the latter case and movable in the former case. Two beam directions B and Bx are illustrated in Figure 5 for the focusing device movable and displaced as shown to position Dx for the latter beam direction.

Again it is possible to have a combination arrangement whereby both the point-of-ray-divergence as well as the optical device D are independently movable, in an arrangement based on that of Figure 5, to position the optical beam through two co-ordinate control axes.

Referring to Figure 6, which serves to illustrate an arrangement where a fixed optical beam B1 is to be deflected in any required direction, a first focusing device D1 is provided to bring the rays of said beam B1 to an image point O, the rays therefrom serving as a point-of-divergence meeting a second focusing device D2 which latter collimates them into the positionable beam B2. The direction of the beam B2 depending upon the relative positions of the two focusing devices D1 and D2, either one or both said focusing devices being movable by suitable means. Any displacement of the first device D1 (if movable) effectively resulting in an equal displacement of the point O on the focal plane F, and the position of the deflected beam B2 being parallel to a line from the displaced point O and projected through the centre C2 of optical symmetry of the second focusing device D2, the situation being analogous to that of Figure 3. A displacement of the second focusing device is analogous to the situation of Figure 4. A two-dimensional positioning arrangement results if means are provided to move the focusing devices along two co-ordinate axes independently, say along X and Y as shown. The focusing devices shown in Figure 6 imply refractive types, namely lenses.

Referring to Figure 7, which illustrates an alternative arrangement to that described with reference to Figure 6, using reflective types of focusing devices, D1 and D2 are side sections of concave (paraboloid) surfaces, instead of symmetrical shapes, to allow the beams or rays to proceed into and out of the arrangement.

Figure 8 serves to highlight a problem which arises in the beam deflecting systems based on the methods described earlier with reference to Figures 6 or 7, and Figures 9 and 10 illustrate corrective measures that may be effected.

Referring first to Figure 8 in which two focusing devices D1 and D2 are provided, (say to effect two-dimensional deflection) an awkward situation arises out of the displacement of the first focusing device, D1, in that the cone of rays diverging from the image point O cannot be intercepted by the second focusing device D2, shown as the unintercepted rays ur. This severely limits the maximum angle of deflection obtainable from the arrangement, but even with smaller displacements of the focusing device D1, a good deal of the cone of rays from O may not be intercepted by the second device D2, resulting in a progressive reduction of the luminous intensity of the deflected beam with increasing displacement of the first device D1. These undesirable effects can be corrected or drastically reduced by placing another focusing device Do on the plane containing the image point O, with its centre of symmetry in line with the beam B1 as shown in Figure 9,

where the cone of rays from O is bent or folded at its apex towards the centre of the second focusing device D2. Referring to Figure 9, the unintercepted cone of rays ur in the absence of Do is shown dotted, the correction angle effected being δ. If the focal length of the "on-image" focusing device Do is correctly chosen in relation to the focal lengths of the other two focusing devices, the cone of rays from O will meet the second device D2 on exactly the same spot regardless of the displacement of DI provided that the point O falls within the boundary of the Do device, resulting in a wide angle beam deflecting system. The correct relation for the focal length f_o of the focusing device Do can be shown to be,

$$\frac{1}{f_o}=\frac{1}{f1}+\frac{1}{f2}$$

where, f_1 and f_2 are the focal lengths of the focusing devices D1 and D2 respectively. Theoretically the focusing device Do has no effect on the cone of rays from O (assuming say a thin lens) other than to cause the said folding of the cone of rays at its apex towards the main axis of the arrangement.

If the focal length f_o of the "on-image" focusing device Do is greater than the expression given above, under-correction will result but nevertheless a drastic improvement will be obtained.

The on-image focusing device Do need not necessarily be a lens (as implied by the drawing of Figure 9) it may alternatively be a concave mirror with the surface of that mirror coinciding with the locus of the image point O; this however requires that the focusing devices D1 and D2 be of a suitable construction for their focal surfaces to coincide with the surface of the said on-image concave mirror, otherwise defocusing will result at certain positions of the focusing device D1. If the displacement of the focusing device D1 is along a straight line only, then the on-image focusing device may be of a cylindrical construction regardless of whether it is of a refractive or reflective type.

A parallel situation arises with the arrangement of Figure 7 with a large displacement of the focusing device D1 which may be corrected as shown in Figure 10 using a reflective type of an image device Do. The D1 device in Figure 10 is shown transferred over to the opposite side, as compared with its position in Figure 7, this being necessary due to the presence of the reflective type of image device Do. The position of D1 in the absence of the on-image device Do as well as unintercepted rays ur by D2, are shown dotted in Figure 10 in order to highlight the effected correction and the relevant correction angle δ.

Referring to Figure 1, as the first focusing device D1 is displaced along a straight line in the direction X shown, the fixed beam B1 is intercepted by the said device along a narrow strip of width (on the said device) equalling that of the beam and consequently it is possible to substantially reduce the mass of that device both by providing a narrow beam and by slicing off the unusable sectors on either side of the said strip, as illustrated in Figure 11 where the removed sectors are shown by a dotted line. Normally the second focusing device D2 cannot be similarly treated, if it moves at right angles to the first device D1, as its entire surface will be required to intercept the movable cone of rays from O, say following a locus which is normal to the direction of motion Y of the second device D2. However, the use of an on-image focusing device offers the additional advantage in that the intercept of the cone of rays from the image point O can be made stationary in space on the plane containing D2, regardless of the displacements of the device D1, thus making it permissible to also slice off unusable sectors of the second device D2 as shown in Figure 12 and reduce its weight considerably.

Figure 13 illustrates the alternative arrangement to that described with reference to Figure 12 when reflective types of focusing devices are used.

Referring to Figure 14, two cylindrical focusing devices of suitable focal lengths are provided mutually at right angles and in close proximity, so that most of the deflected rays emerging from the first cylindrical device D1 may be intercepted by the second cylindrical device D2, either or both said devices being movable to deflect an optical beam as required. This is an alternative method of obtaining approximately similar results to those described with reference to Figures 9 and 12, without the use of an on-image focusing device. The combination of the two devices D1 and D2 of Figure 14 virtually forms a single lens serving to collimate the rays from the point-of-ray-divergence O, into any desired direction B, through two independent co-ordinate control axes X and Y as shown. It is also possible to use this arrangement in reverse with a fixed optical beam entering the D1 and D2 combination to move an image point O, which latter may serve to supply the rays to be collimated by a further optical device, following the principle of Figure 3. The focusing devices as shown in Figure 14 imply cylindrical lenses, their focal lengths differing by the distance between them.

Referring to Figure 15, which illustrates the reflective equivalent of the arrangement in Figure 14, two cylindrical mirrors D1 and D2 are used in close proximity to effect beam deflection. One possibility of overcoming obstruction difficulties which arise regarding the rays proceeding into and out of this latter arrangement, is to direct the incoming rays

from point O' to proceed to the first cylindrical mirror D1 at a suitable angle so as to clear the other cylindrical mirror D2 while arranging for a double reflection to occur on the mirror D1 so that the outgoing beam may emerge unobstructed out of the arrangement regardless of the displacements of the two cylindrical mirrors. The double incidence of rays on D1 necessitates that the focal lengths of the two mirrors be suitably related so that the arrangement may collimate the rays from O without astigmatism.

Referring to Figure 16, a fixed focusing device D and a cathode ray tube crt are provided, the latter serving to supply a movable luminous point O' anywhere on its fluorescent screen by means of the electron beams deflecting system thereof. The realisation of an electronically operated optical beam positioning arrangement involves the application of the principle described earlier with reference to Figure 3 (or the appropriate Figure 5 equivalent) and is suitable for either of the selector switching systems of Figures 1 or 2. The fixed focusing device D serves to collimate the rays emanating from O into the optical beam B in any desired direction. The cathode ray tube may either be a high vacuum thermionic or a cold-cathode gas filled type and the electron beam deflecting system may be either electrostatic or electromagnetic according to preference. The simply illustrated focusing device D may either be of the refractive type comprising one or more elements and/or any reflective type of any suitable combination system for the production of a collimated optical beam substantially free from spherical aberration, such a parabolic reflector or a spherical reflector in association with a Schmidt or Maksutov corrector plate.

An opto-electronic closed-loop (feedback) position-servo control system is required to position accurately the optical beam in the direction of the selected photo-electric receiving unit as well as to maintain that position, as this arrangement does not normally possess position memory, (although it is possible to provide a special cathode ray tube in which the electron beam may rest in any one of various possible fixed positions.

As the intensity of the luminous points on the fluorescent screen of a cathode ray tube may be modulated through the control grid to cathode potential difference, it is possible to provide an integrated sending and optical beam positioning unit suitable for application in the selector switching system of Figure 2. In such a case the persistance of the fluorescent coating on the screen of the cathode ray tube must be low enough to enable the trace to respond to the highest frqueency component in the intelligence signals that it is desired to transmit.

Alternatively, directly operating, open-loop electronically operated beam positioning means may be required in certain applications of the present invention based on either of the switching systems of Figures 1 or 2, a preferred arrangement of which will be described with reference to Figure 17. Referring to Figure 17, a cathode ray tube crt is used to provide a positionable luminous point on its screen, light rays therefrom being collimated into an optical beam by means as described earlier with reference to Figure 16. Although an electrostatic electron beam deflection system is chosen for ease of explanation and illustration, the operating principles to be described may easily be modified to suit a magnetic electron deflection system. Each set of deflection plates in the cathode ray tube, are supplied by non-coincident pulses from a number of position controlling channels, the pulse repetition frequency of the said channels being in ascending binary order, any combination of position controlling channels being selectable through associated cross-points cp1, cp2, cp4, cp8, etc. The pulses admitted only through the operated cross-points are amplified, if required by the amplifier A, and passed through an averaging filter AF preferably after a pulse amplitude limiter PAL, so that the average value of the pulses from the selected position controlling channel combinations provides the potential for the deflection of the electron beam. The system is essentially a binary digital to analog translator serving to position the luminous point on the fluorescent screen of the cathode ray tube in accordance with the digital command applied to the system. The averaged potential may assume two different values depending on whether or not pulses are admitted from the units channel, two of higher order from the twos channel and so on, the total possible combinations following the binary expression 2^n, where n represents the number of position controlling channels provided in the system, thus for five channels 32 defined optical beam positions are possible in that particular co-ordinate axis. The other set of plates may be similarly supplied and the total number of co-ordinate beam positions will be $2^{(n+m)}$ where m is the number of position controlling channels provided for the other co-ordinate; if $n=m=5$ then 1024 beam positions may be effected.

As this arrangement may be subject to slow drift in its electron-beam deflection sensitivity, it may be automatically recalibrated at regular intervals against some suitable optical or other reference, preferably on a time-shared basis with other such arrangements in the selector switching system.

Modifications to the arrangement of Figure 17 to provide an integrated time-shared sending and optical beam positioning system suitable for application in the time-shared common-linking units of the time-division multiplexed swtching system of Figure 2, will be

described with reference to Figure 17. The averaging filter AF and limiter PAL are dispensed with and the cross-points cp1, cp2, cp4, cp8 etc., are converted to "and" position-controlling gates, pulsed to open according to any required coincident combination. The pulses provided by the PULSE SUPPLY are of identical width and repetition frequency in all of the position controlling channels but of different amplitude for each said channel following an ascending binary order, thus for example, the amplitudes of the pulses in the TWOS, FOURS and EIGHTS channels are respectively twice, four times and eight times the amplitude of the pulses in the UNITS channel.

The repetition frequency of said pulses is identical to those for the "and" gates in the time-division-multiplex switching system of Figure 2, with the leading edges of said pulses slightly preceding and the trailing edges slightly following the corresponding pulses in the system of Figure 2, the said leading and trailing edges of the former pulses occurring during the position control intervals PCI-1, PCI-2, PCI-3, . . . PCI-M of the system of Figure 2. The required instantaneous beam deflection may be obtained by the corresponding coincident opening of the position controlling "and" gates (cp1, cp2, cp4, cp8, etc.) which are pulsed to open by pulses of identical width and frequency to those supplied in the various aid position controlling channels.

Other possibilities for a positionable luminous point-of-ray-divergence (or light source) may be either an electroluminescent matrix (not shown) or some gas-filled glow device (not shown) whereby the glow may be positioned by suitable means, in place of the cathode-ray tube in the arrangement of Figure 16. Opto-electric closed-loop position maintenance control may not be required with such arrangements if the positions of the luminous point are defined by the geometric construction of the devices. Such electroluminescent or gas-filled glow devices, being by nature modulatable, may also serve to provide integrated sending and optical beam positioning units, provided their speed of operation is compatible with the requirements of the particular application of the invention.

In certain applications of the present invention involving the system of Figure 1, it may be convenient to utilise electro-mechanical means to effect displacement of optical elements relative to any preferred light-ray grouping. Said electro-mechanical means involving some suitable mechanism which is electro-magnetically actuated either following known techniques, such as for example driving motor or ratchet-and-pawl arrangements or employing methods suggested further on in this specification. The exact positions to which the optical beams must be set as required, may be assured either by direct open-loop arrangements involving accurately defined mechanical position guides and stops, or alternatively through an opto-electric closed-loop position-servo system, preferably time-shared to serve all the beam positioning units sequentially one at a time for a centralized control unit.

Figures 18 to 25 illustrate the evolution, operation and means therefor of suggested open-loop electro-mechanically operated beam positioning mechanisms directly actuated by magnetic forces exerted by electro-magnetic means or magnetisable elements, which may be preferred in certain applications of this invention.

Referring first to Figure 18, which serves to explain the underlying principle of the suggested open-loop direct beam-positioning arrangements an optical element E is movable by magnetic means (not shown in this Figure), in the X direction indicated, between a pair of stops g2 and h2. The said optical element E is mounted in a rigid structure comprising the two parallel end members g1 and h1 attached between the brackets k1 and l1. A rod or bar i1 (serving as a sort of an armature) of magnetically attractable material, preferably of low magnetic retentivity such as soft iron, is also attached to the said structure by some means, which may conveniently be extensions of the said brackets k1 and l1, so that it may be possible to attract and move magnetically in either required direction the bar i1 together with the attached thereto structure containing the said optical element E. The movable structure containing the said optical element E may rest and slide on any suitable bearing arrangement (not shown in this Figure) in the direction X.

To illustrate the movement of an optical element related by way of example to arrangements such as those described with reference to Figures 12 or 13, the drawing of Figure 18 shows a focusing device, but the said movable structure may contain any other optical element, the latter term being as defined earlier in this specification.

The structure containing the optical element may only rest in one of two positions either with member g1 bearing up against stop g2, as shown, or with member h1 bearing against stop h2. If the structure containing the optical element is moved to the other position, bearing against stop h2, the optical beam will move accordingly by a proportional amount.

The pair of stops g2 and h2 may be made jointly movable by having them rigidly assembled into a second structure by means of brackets k2 and l2 together with an associated magnetically attractable bar i2. The latter stop pair may then assume one of two possible positions, between a third pair of stops g3 and h3, Figure 18 showing the

position in which member g2 is bearing up against stop g3. Should the second stop-pair be moved until member h2 comes to rest against stop h3, it will then be possible to obtain two additional beam positions by moving the structure containing the optical element once again between the g2 and h2 stops.

This system may be regarded as an electromechanical binary beam-positioning system in which each successive pair of stops contributes a higher order in the numeral sequence of the optical element and associated beam positions. Thus with two pairs of stops (one movable and the other fixed) $2\times2=4$ beam positions are possible, with three pairs of stops (two movable and one fixed) $2\times2\times2=8$ positions are possible and in general with n pairs of stops (one fixed and the others movable) 2^n beam positions may be obtained.

The sequential arrangement of the stop-pairs is unimportant, the optical element may alternatively be contained by an outermost structure movable and enclosing the other structures containing the stop pairs while the innermost pair of stops is fixed in space.

Figure 19 shows an alternative convenient combination of optical element and stop-pairs in which the individual structures are of equal width and lie end-to-end in series instead of enclosing one another. Referring to Figure 19 a suitable number of movable stop-pair structures and a structure containing the optical element E are provided which rest and slide along two parallel guides, grooves or rails or the like r1 and r2. Each stop-pair structure at one end is provided with a U-like member u the inner surfaces g and h of which serve as the stops for the member j of the adjacent structure and at the other end is provided with the magnetisable bar i, the latter being attached to or forming part of member j of that particular structure. A pair of brackets k and l serve the combined function of holding the other two members together into a rigid structure as well as providing the mating surfaces sliding between the said grooves or rails r1 and r2 respectively. The structure containing the optical element is similarly provided with a magnetisable bar i1 joined to or forming part of a member j1 as well as with the brackets k1 and l1 which latter serve the combined functions of holding the structure together as well as providing the mating surfaces which slide between the said grooves or rails r1 and r2. The lengths of the respective brackets in the various structures conform with the clearances required between adjacent magnetisable bars to accommodate the actuating electro-magnetic devices.

All the stop pairs in either the Figure 18 or 19 arrangements need not be mechanically coupled together into a single group; two or more separate groups may be provided with optical coupling between the groups. For example, an additional group of stop-pairs may be associated with the point-of-ray-divergence so as in effect to move the latter. In practice, a large group of mechanically coupled stop-pairs is undesirable as it will create problems regarding the accommodation of the electro-magnetic means necessary to move the stop-pair structures.

A two-dimensional optical beam positioning arrangement (suitable for use in selector switching system of Figure 1) based on any of the methods described with reference to Figures 12 to 15, may be operated directly on open-loop by using either arrangement described with reference to Figures 18 or 19 to move and position the focusing devices D1 and D2 along the two-co-ordinate axes X and Y. More than one group of stops-pairs, preferably optically coupled by suitable means, may be used for each co-ordinate axis. If n is the number of stop-pairs in one co-ordinate direction and m in the other, the total number of positions which the optical beam may assume will be $2^{(n+m)}$, thus for example if $n=m=3$ then 64 positions are obtainable. The displacements between the stops must conform rigorously to the spacial distribution of the various units in the optical chamber of the selector switching system, so that the optical beams fall exactly on the selected opto-electrical transducers.

If the structure of stops and optical elements are arranged so as to rest and slide horizontally, then once set to any selected position, they will retain that position due to gravity, the system then inherently possessing position memory, although it is not essential to have such an arrangement with the actuating systems of Figures 22 to 25 to be described further on in this specification.

Referring to Figure 20 a number of stop frames fr1, fr2, fr3, . . . are provided surrounding one another, each comprising four inner and outer sides the, optical element E being mounted on another frame frE. The frame frE is restricted to move only along the axis X by any suitable means (not shown) while being able to assume two different positions within the stop frame fr1 between the sides h1 and g1 serving as a stop-pair. The four inner sides in each of the frames fr2, fr3, . . . serve as stops for the adjacently surrounded frame so that the latter may assume four different positions bearing up against the four inner corners of the immediately surrounding frame. Thus, the frame fr1 may assume four different positions against the inner corners of the frame fr2 and the frame fr2 may similarly assume four different positions within the frame fr3.

If n is the number of the stop-frames, the innermost stop-frame fr1 can thus assume $4^{(n-1)}$ positions, or the number of movable stop structures is reduced by a factor of 2

as compared with the arrangements of Figures 18 or 19.

Each stop-frame is movable by the associated actuating electro-magnetic means (not shown) along the two component directions X and V. The two outer sides go1 and ho1 of the innermost stop-frame fr1 are inclined at an angle α (parallel to the direction V) with respect to the inner sides g1 and h1, the corresponding sides of all other stop-frames being parallel to the said outer sides go1 and ho1 of the frame fr1.

Figure 21 shows at an enlarged scale (3 : 1) the positions which the various frames may assume individually and collectively relative to arbitrary references. Diagram (a) refers to the positions of stop-frame fr2 with respect to frame fr3 diagram (b) refers to the positions of stop-frame fr1 with respect to frame fr2; diagram (c) refers to the positions of the optical element with respect to frame fr1; diagram (d) refers to the positions of frame fr1 in conjunction with the displacements of frame fr2 with reference to frame fr3; and diagram (e) refers to the overall effect regarding the positions which the optical element may assume along the X axis due to the combinations of positions of all the frames.

To obtain equidistant displacements of the optical element along the X direction, the various inter-frame displacements allowed along the X and V axes and the value of the angle α must be correctly interrelated. The dimension x (shown in both Figures 20 and 21) represents the least inter-frame displacement along the X axis and v that along the V axis. The other interframe displacements must be related to x and v by progressive mutiples of 2 in the respective directions. Thus with 3 frames the inter-frame displacements must be, x, 2x and 4x along the X direction, and v and 2v along the V direction. It can be shown that the angle α may be obtained from the relation,

$$\sin \alpha = \frac{1}{2^{(n-1)}} \cdot \frac{x}{v}$$

The total number of equidistant positions which the optical elements may assume along the X axis under these conditions will be twice the number of positions of the innermost stop-frame fr1, which latter may be expressed as $2^{(2n-1)}$. Thus with an arrangement as in Figure 20 comprising 3 stop-frames (two movable and one fixed), $2^5=32$ equidistant positions of the optical element and consequently of the optical beam are possible along a straight line. With two such arrangements mutually at right angles, involving any of the methods described with reference to Figures 12 to 14, a two-dimensional optical beam positioning system will result enabling 1024 defined beam positions. On the other hand a two-dimension beam positioning arrangement using four stop frames would yield 128 positions per co-ordinate or a total of 16384 defined beam positions.

With any of the arrangements of Figures 18 to 20 the actuating forces are arranged to progressively increase for the movable structures, starting from that of the optical element, by some suitable factor (say about 3) so that the sum total of the forces acting from the direction of the optical element may never overcome the force acting on any particular stop structure.

The inevitable limitation of electro-mechanical positioning system is their comparatively slow response time as regards their displacement, following the application of the actuating force, because of their inertia and no matter how small in size or mass they may may be constructed, a response time of a few milliseconds at least may be expected. Suitable means can be provided which may rapidly store or retain the actuating magnetic force following a very short control period from a centralized control-unit, the physical displacement of the stop-pairs or stop-frames and optical elements in their respective structures being allowed to take place on their own time thereafter, while the centralized control unit may be performing many other operations in the meantime. This may be advantageously obtained by the use of magnetizable cores possessing high magnetic retentivity, such as ferrites, so that the control time becomes only that necessary to effect the retainable magnetisation, (of the order of a microsecond) as for example the practice adopted with the control of the sealed dry-reed relay commercially known as the "fereed."

Referring to Figure 22 which suggests one possible form of an electro-magnetic actuating arrangement to move the stop structures or stop frames and the focusing elements, so as to effect direct open-loop optical beam positioning, three magnetizable cores mg, mh and mc are provided which are shunted across their respective ends by pole-pieces p and q, each said pole-piece carrying a pair of projections pg, ph and qg, qh respectively. The magnetizable cores mg, mh and mc are of high magnetic retentivity material, such as ferrite, while the pole-pieces and their associated projections are of low retentivity material, such as soft iron etc. The polarity means of an electric pulse applied to its associated coil cc, say by applying positive and negative pulses to the said coil at the terminal Tc of the latter. The outer cores mg and mh are magnetised so as to always exhibit fixed mutually opposite magnetic polarities, such as may be seen by comparing the magnetic circuits of Figures 23 and 24, either by being magnetized by always identical pulses, applied to the terminal Tgh of the associated coils cg and ch, synchronously

mit modulated optical pulses to the selected terminating unit, by means of the time-shared positioning of the optical beam for photo-electric demodulation in the latter said unit.

6. An opto-electric selector switching system as claimed in Claim 5, wherein an electrical time-division-multiplex circuit arrangement is provided with the various "and" gates supplying pulse modulated electrical signals to the time-shared common linking units through the appropriate highways, the said pulses modulating the time-shared optical beams to establish opto-electric time-division communication channels between the external network outlets.

7. An opto-electric selector switching system as claimed in Claim 6, wherein a separate time-shared common linking unit is assigned to each group highway, the electrical circuit terminals being allocated fixed channel pulses and grouped so that each highway is assigned to a group of terminals allocated dissimilar channel pulses comprising all of the channels, all of the terminals being scanned sequentially through the "and" gates in all the groups and with an optical beam permanently allocated to each said group highway, any required beam position is possible for any one channel pulse, which signifies that the total number of space-separated time-division channels equals the total number of terminating circuits.

8. An opto-electric selector switching system as claimed in any of Claims 4 to 7 wherein the said time-shared common linking units comprise a combined sending and beam positioning device including a modulatable light source.

9. An opto-electric switching system as claimed in Claim 8, wherein said combined sending and beam-positioning device consists of an intensity modulated cathode ray tube and a collimating arrangement to form the rays of the spot on the cathode ray tube screen into an acceptably narrow beam positionable by virtue of the deflection of the said spot, means being provided in the common equipment of the switching system to automatically calibrate the deflection of the luminous spot on the screen of the said cathode ray tube and further means being provided to allow sufficient positioning time prior to the arrival of each modulating pulse.

10. An opto-electric selector switching system as claimed in Claim 9 wherein the deflection of the cathode ray tube beam and consequently of the optical beam, is effected by coincident combinations of control pulses of different amplitudes, said control pulses being of identical repetition frequency to the channel pulses of the time-division-multiplex circuit.

11. An opto-electric selector switching system as claimed in Claim 10 wherein the amplitudes of said control pulses for the beam deflection follow a binary ascending order and their width slightly exceed the width of the multiplex channel pulses in order that the beams be positioned each time slightly ahead of the arrival of the modulated channel pulses.

12. An opto-electric selector switching system as claimed in Claim 2 wherein optical beam positioning by the said beam positioning units is effected on the basis of a relative displacement between an optical element and a grouping of light rays, said grouping including an optical beam and/or a cone of rays diverging from a light source or an image point, said optical element being a focusing device of spheroidal or cylindroid surfaces and said relative displacement being in a plane normal to the optical axis of said focusing device, means being included in said beam positioning units to effect said displacement.

13. An opto-electric selector switching system as claimed in Claim 12 wherein the beam-positioning unit includes two focusing devices separated by the sum of their focal length and movable mutually at right angles, an incident beam being caused to pass successively through both focusing devices, the first causing the beam to be focused to an image point movable by the translational displacement of that device and the second focusing device collimating the rays diverging from said image point into a positionable beam, where the translational displacement of the latter said focusing device serves to deflect the latter beam along one co-ordinate direction with direct proportionality while the translational displacement of the first said focusing device serves to deflect the beam directly proportionally in the other co-ordinate direction, means being provided in the said beam-positioning unit to effect the required displacements of the said pair of focusing devices.

14. An opto-electric selector switching system as claimed in Claim 13 wherein a third focusing element is placed on the image plane serving to return towards the centre of the second focusing device the cone of rays from said image point, which otherwise tends to move out of the bounds of the second focusing device as a result of a displacement of the first focusing device, i.e. serving to correct the deviation of the cone of rays from the centre of the second focusing device, otherwise occurring due to the displacements of the first focusing device, so as to provide a wide angle beam deflecting system, the said beam positioning focusing devices being provided in narrow strip form of substantially reduced weight.

15. An opto-electric selector switching system as claimed in Claim 14, whereby means are provided to accurately position the said beam deflecting focusing devices on an open-loop basis by means of magnetically actuated

movable stops formed into an ascending sequential mechanical binary system which defines in combination a plurality of accurate positions, anyone of which may be obtained by selecting the corresponding binary combination.

16. An opto-electric selector switching system as claimed in Claim 15, in which the said stops are formed into a number of stop frames surrounding one another so that each said stop frame may assume four different positions bearing up against the four inner corners of the immediately surrounding frame, each said beam deflecting focusing device being guided by a system of such frames to assume any one of a plurality of accurately defined position according to the selected combinations of mutual positions among the said frames.

17. An opto-electric selector switching system as claimed in Claim 15 or Claim 16 in which means are provided which rapidly establish and thereafter retain the actuating magnetic forces as required to position said movable stops or stop-frames following a very short controlling period, said means comprising high magnetic retentivity cores, such as ferrites in arrangements which may be alternatively magnetized by means of short electrical pulses applied to their associated coils.

18. An opto-electric selector switching system as claimed in any of Claims 12 to 14 in which the displacement of a beam deflecting focusing device is effected under a centralised closed-loop opto-electric servo control, with means individually provided to displace any said beam deflecting focusing device.

19. An opto-electric selection switching system as claimed in Claim 18 in which said means individually provided to displace said focusing devce comprise vibrating supports upon which said device is resting, said supports being provided with means whereby they may move in either required direction fast out of and return slowly to their normal fast movement the slip of the said focusing device due to its inertia is greater than during the slow return motion of the said supports thus resulting in a net displacement of the said optical device.

20. An opto-electric selector switching system as claimed in Claim 19, said means causing said vibration of the supports comprising an electro-magnetic drive-in unit, which said latter unit imparts the said vibrational motion through the application of a saw-tooth waveform to the associated coil.

21. An opto-electric selector switching system as claimed in any of Claims 18 to 20 wherein the servo-control equipment includes partly centralized and partly distributed equipment at the various beam positioning units serving to obtain information regarding the position of any optical beam during the beam positioning interval so that the error may be determined and the required correction effected to bring the optical beam to its required destination, the latter said equipment including co-ordinate position discriminator sets of photo-electric cells, commonly available along a column and a row lying just outside the area occupied by the terminating sending-receiving units and an optical beam positioning analyser provided at each beam-positioning unit comprising means to separate a beam into two co-ordinate components one corresponding to the row and the other to the column of the terminating unit to which the beam is being directed, each said co-ordinate component meeting the corresponding co-ordinate position discriminator sets of photo-electric cells which latter determine the position of the beam, the two said co-ordinate components being obtained by separating the beam into two parts ahead of the beam deflecting focusing devices of a beam positioning unit by means of a translucent mirror and thereafter guiding one said part to by-pass the first and the other said part to by-pass the second beam deflecting focusing device to thus obtain two separately and independently deflectable beam components which are collimated by additional fixed auxiliary devices into the said two co-ordinate components meeting the said corresponding discriminator sets of photo-electric cells.

22. An opto-electric selector switching system as claimed in Claim 12, wherein the beam positioning unit comprises a cathode ray tube, the latter serving as a combined beam originating and beam positioning device by virtue of the positionable luminous spot on the screen thereof in combination with a collimating arrangement, the deflection of the electronic beam and consequently of the optical beam being effected by means of a binary digital to analog arrangement in which a selectable combination of non-coincident pulses from a number of position controlling channels are passed through an averaging filter to obtain the average value of the selected combination which latter serves to deflect the electron-beam, the said pulses from different controlling channels being arranged in ascending binary order.

23. An opto-electric selector switching system as claimed in Claim 1, in which in said common equipment the optical-beam originating supplying means yields a good parallelism among the rays constituting said optical beams, said beam originating means comprising at least one optical source of small dimensions and at least one optical collimating arrangement of very large focal length as compared with the dimensions of said source, light rays proceeding from said small optical source being collimated by said collimating arrangement to yield one or more beams of good parallelism satisfying the requirements of the System.

24. An opto-electric selector switching system as claimed in Claim 23 in which said optical beam originating means include at least one optical reducing arrangement, i.e. an inverted microscope, serving to provide indirectly an optical source of extremely small dimensions, the latter being a substantially reduced real or virtual image of any otherwise according to dimensional requirements non-acceptable physical light source.

25. An opto-electric selector switching system as claimed in Claim 1, in which said common equipment comprises at least one LASER-beam source to supply coherent light beams to the said switching system serving to effect optical interconnecting paths therein.

26. An opto-electric selector switching system as claimed in Claim 2, in which said common equipment comprises at least one beam-dividing distributor comprising a plurality of redirecting non-focusing optical elements such as mirrors or prisms, serving to divide up one or more wide main beams of good parallelism incident thereto into a plurality of narrow optical beams for further use by said common equipment, each said optical element contributing to this and by removing and redirecting a different cross-sectional small fraction of said incident-wide beam.

27. An opto-electric selector switching system as claimed in Claim 26, in which said wide beam is of LASER origin obtainable through beam-widening means, said beam-widening means comprising an optical element to bring to a real or virtual image point the rays of an incident narrow LASER beam and a collimating arrangement of larger aperture and of longer focal length to the former said element, to form the said wide beam.

28. An opto-electric selector switching system as claimed in any one of Claims 9, 22, 23 or 27 wherein the said collimating arrangement consists of a parabolically shaped reflector to substantially minimise spherical aberration.

29. An opto-electric selector switching system as claimed in any one of Claims 9, 22, 23 or 27 wherein the said collimating arrangement consists of a concave spherical reflector together with a Schmidt aspherical corrector plate to minimise spherical aberration.

30. An opto-electric selector switching system as claimed in any one of Claims 9, 22, 23 or 27 wherein the said collimating arrangement consists of a concave spherical reflector together with a Maksutov spherical corrector plate to minimise spherical aberration.

31. An opto-electric selector switching system as claimed in Claim 2, wherein means are provided in the said common equipment to supply a plurality of narrow beams, said means comprising a combined collimating and beam dividing distributor including a small optical source of light and a plurality of small aperture optical focusing elements of very large focal length in comparison with the dimension of said small optical source, said focusing elements being arranged side by side in a honyecomb fashion with all the focal planes containing the said small optical source a different narrow beam of good parallelism being obtained from each said focusing element, any one of the latter inherently being substantially free from spherical aberration by virtue of its very small aperture to focal length ratio.

32. An opto-electric selector switching system as claimed in Claim 31, wherein the arrangement stated under Claim 24 is used to obtain a substantially reduced image of a dimensionally according to requirements non-acceptable physical light source.

33. An opto-electric selector switching system as claimed in Claim 2, wherein means are provided in the said common equipment to supply a plurality of coherent light beams, said means comprising a combined collimating and beam-dividing distributor including a point source of coherent light of LASER origin and a plurality of small aperture focussing elements with a comparatively large focal length arranged in honeycomb fashion with all their focal planes containing the said point source, a different narrow beam of very good paraellism being obtained from each said focusing element, any one of the latter inherently being substantially free from spherical aberration by virtue of its very small optical aperture to focal length ratio, said point source of coherent light being obtainable by bringing to a real or virtual image point the rays of a LASER beam by means of a focusing element.

34. An opto-electric selector switching system as claimed in Claim 2, wherein the said narrow optical beams are subsidiary beams of LASER origin obtainable from at least one main narrow LASER beam, said common equipment including at least one beam-separating distributor to separate a plurality of said subsidiary beams from the said main LASER Beam, said beam-separating distributor consisting of a plurality of transmission mirrors each said latter separating intensity-wise an incident beam into two other proceeding in different directions, one of said two beams being the reflected fraction of and the other being the transmitted fraction of said incident beam, the said process beiing sequentially repeated to yield said plurality of narrow beams for further use by said common equipment.

35. An opto-electric selector switching system as claimed in Claim 12, wherein the beam-positioning unit includes two focusing devices of cylindroidal surfaces in close proximity movable mutually at right angles, an incident beam being caused to pass successively through both focusing devices each of which said devices serving to deflect the beam

along a different co-ordinate direction in direct proportionality to the translational displacement of the said focusing device of cylindroidal surface.

36. An opto-electric switching system as claimed in Claim 2, wherein the wide angle retrodirective reflector included in said sending section consists of at least one internally reflecting right solid angle comprising three mutually perpendicular plane surfaces.

37. An opto-electric selector switching system as claimed in Claim 2, wherein the said wide angle retrodirective reflector included in said sending sections consists of an auto-collimator comprising an additional focusing device on the internal focal surface of the auto-collimating element serving to maintain the reflected cone of rays confined within the bounds of the auto-collimator element over a wide angular range of beam incidence.

38. An opto-electric selector switching system as claimed in Claim 2, wherein means are provided which prevent the light of the unmodulated beam from masking that of the modulated beam at the opto-electric demodulator.

39. An opto-electric selector switching system as claimed in Claim 38, wherein said means consist of pulsing or chopping in anti-phase at a high frequency, the two beams emanating from each common linking unit so that the modulated beam may be detected separately by the opto-electric demodulator, the unmodulated beam simply adding an average component to the electrical output.

40. An opto-electric selector switching system as claimed in Claim 38, wherein said means include the utilization of linearly polarized beams together with cross-oriented wide angle polarizing filters situated in front of the photo-electric transducers so as to cancel the unmodulated beam and thus prevent it from reaching the said opto-electric transducer, whereas the modulated beam being rotated about its axis by means included in the system is oriented in a manner which permits its transmission to the said polarizing filters for opto-electric demodulation by the said opto-electric demodulators.

41. An opto-electric selector switching system as claimed in Claim 40, wherein said means rotating the beam about its axis is either situated within the common linking units or else the rotation is effected at the sending units if the latter comprise an electro-optical modulator utilizing a doubly refracting element, in which latter case the said polarizing filters serve the additional function of analyzers.

42. An opto-electric selector switching system substantially as hereinbefore described with reference to the accompanying drawings.

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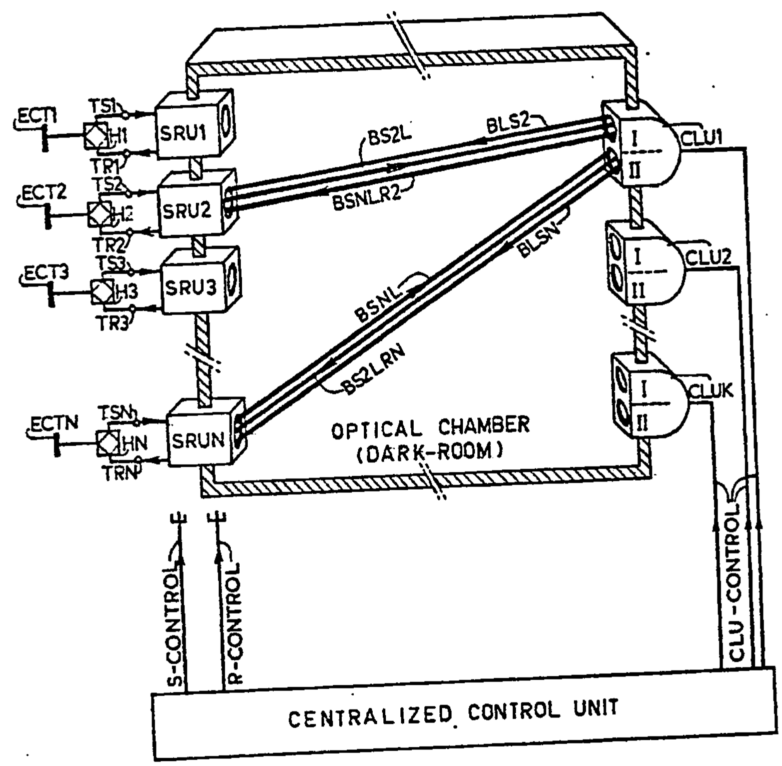
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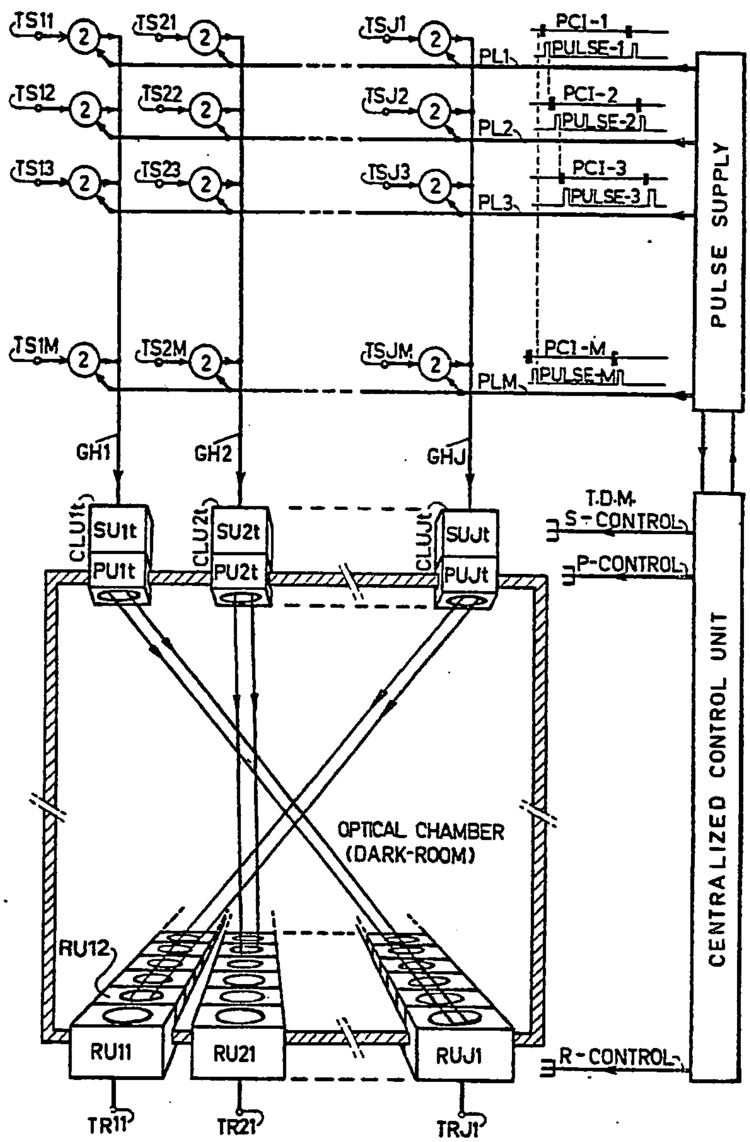
ECTN
TSN
HN
SRUN
TRN
BS2L
BLS2
BSNLR2
BLSN
BSNL
BS2LRN
I
II
CLU1
CLU2
CLUK
OPTICAL CHAMBER
(DARK-ROOM)
S-CONTROL
R-CONTROL
CLU-CONTROL
CENTRALIZED CONTROL UNIT

FIG_1_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PC1-1
PULSE-1
PL1
TS12
TS22
TSJ2
PC1-2
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TS13
TS23
TSJ3
PC1-3
PULSE-3
PL3
PULSE SUPPLY
TS1M
TS2M
TSJM
PC1-M
PULSE-M
PLM
GH1
GH2
GHJ
T.D.M.
S-CONTROL
P-CONTROL
CLU1t
SU1t
PU1t
CLU2t
SU2t
PU2t
CLUJt
SUJt
PUJt
CENTRALIZED CONTROL UNIT
OPTICAL CHAMBER
(DARK-ROOM)
RU12
RU11
RU21
RUJ1
R-CONTROL
TR11
TR21
TRJ1

FIG. 2.

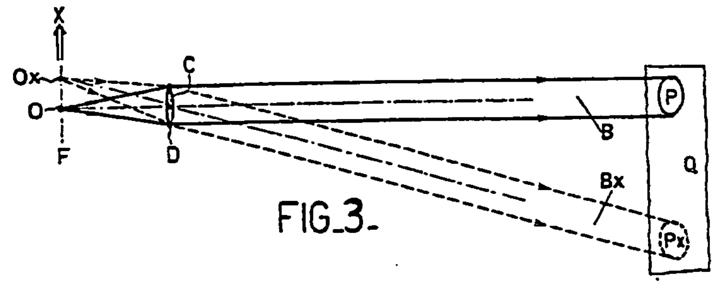


FIG.3.

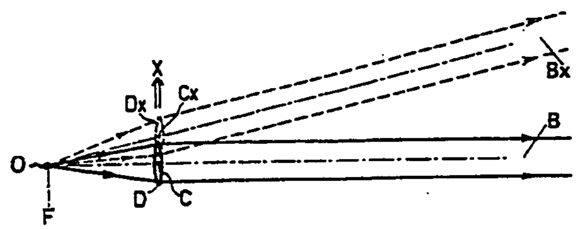


FIG.4.

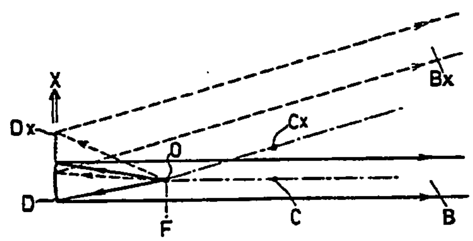


FIG.5.

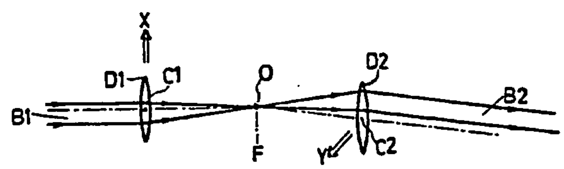


FIG.6.

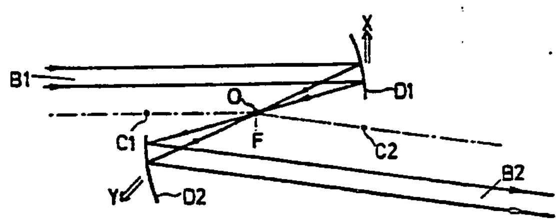


FIG.7.

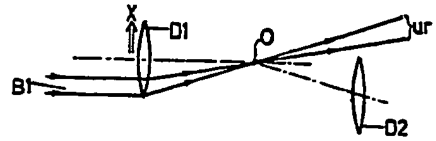


FIG. 8.

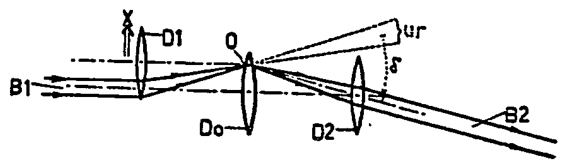


FIG. 9

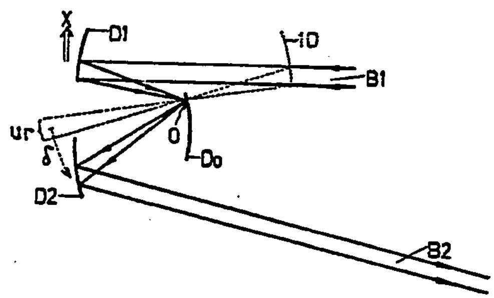


FIG. 10.

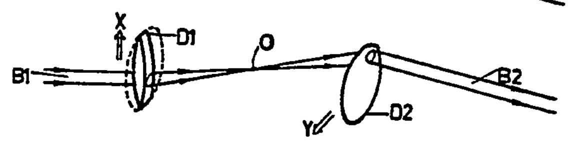


FIG. 11.

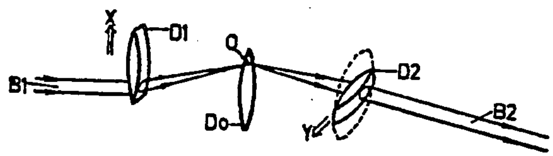


FIG. 12.

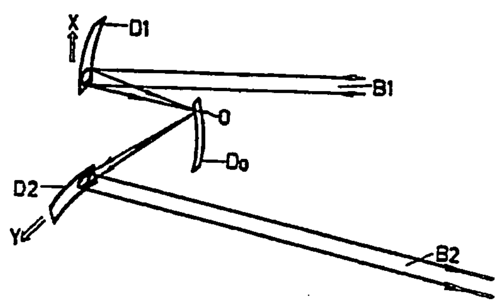


FIG. 13.

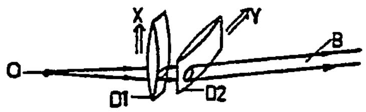


FIG_14_

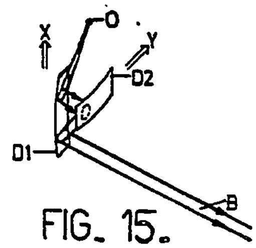


FIG_ 15_

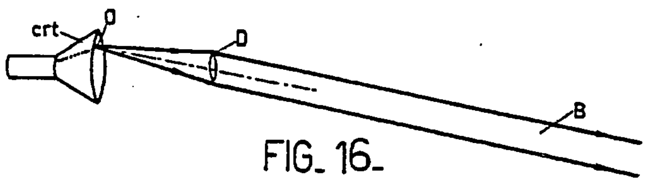


FIG_ 16_

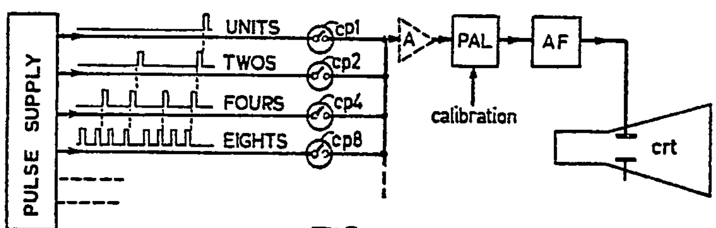


FIG_17_

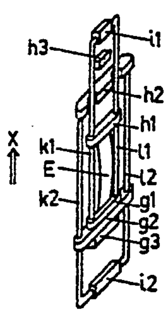


FIG_ 18_

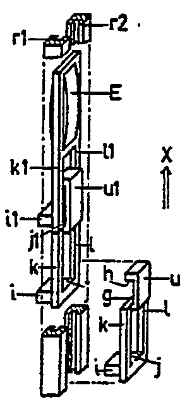


FIG_ 19_

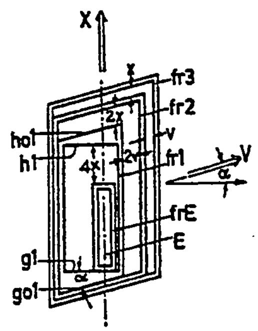


FIG_ 20_

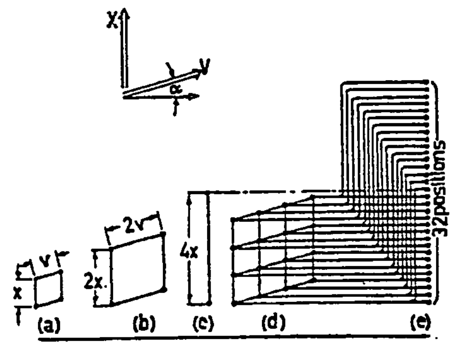


FIG_21_

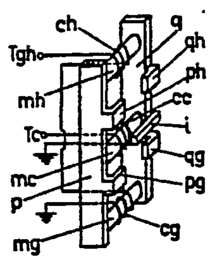


FIG_ 22_

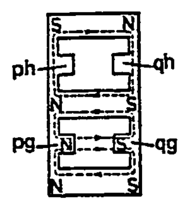


FIG_23_

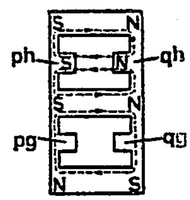


FIG_24_

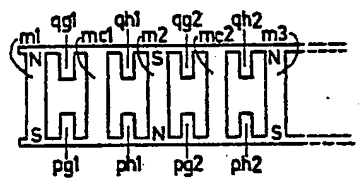


FIG_25

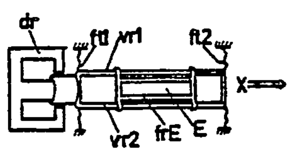


FIG_26_

FIG_27_

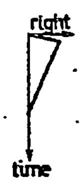


FIG_28_

1160546 COMPLETE SPECIFICATION

10 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 7

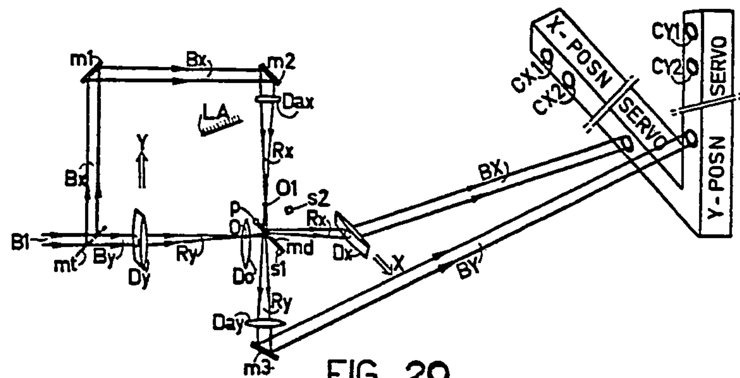


FIG_29_

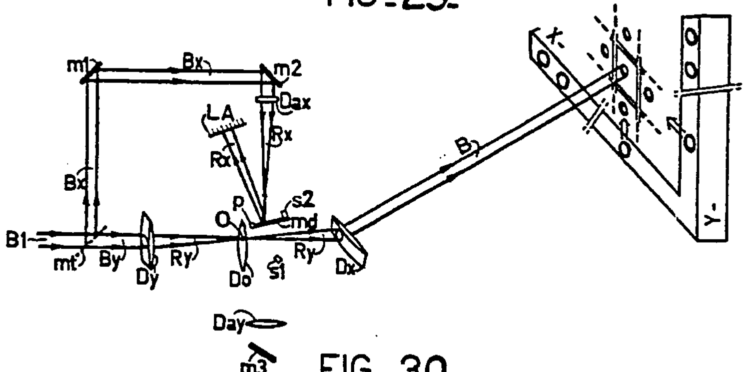


FIG_30_

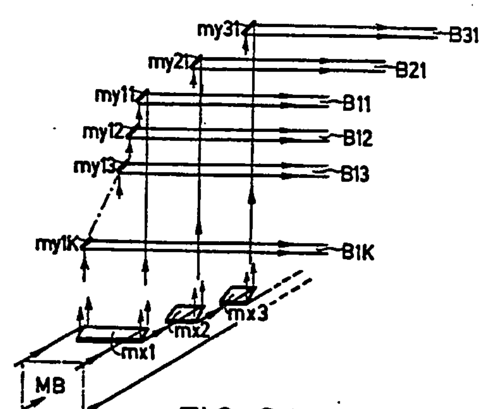
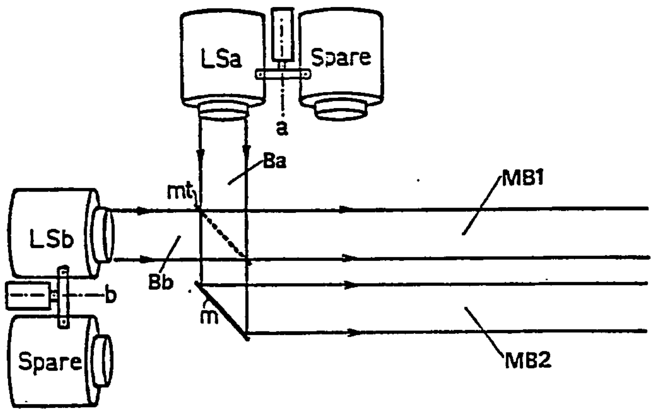


FIG_31_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m
Spare
MB2

FIG_32_

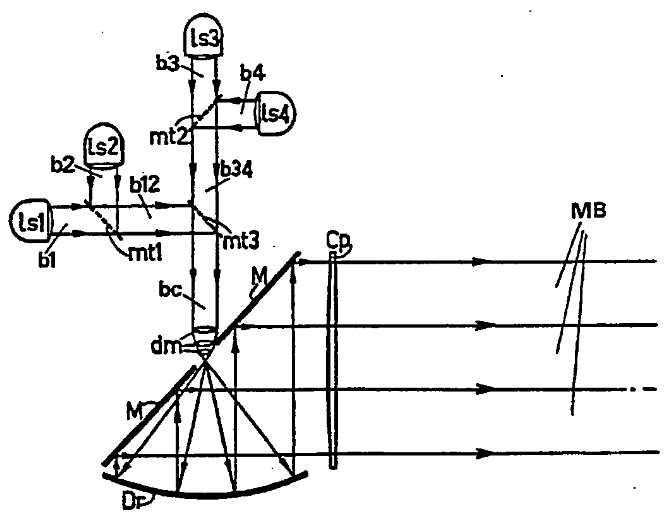
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FIG_33_

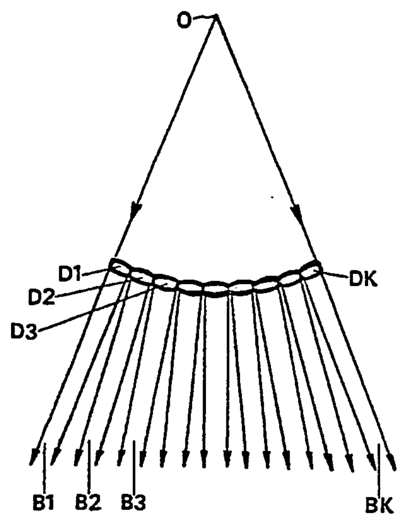

FIG.34.

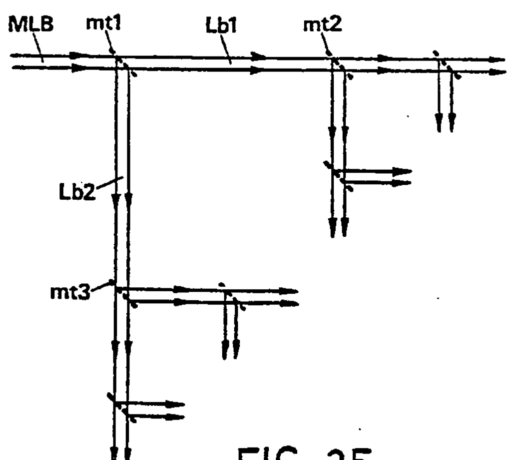

FIG.35.

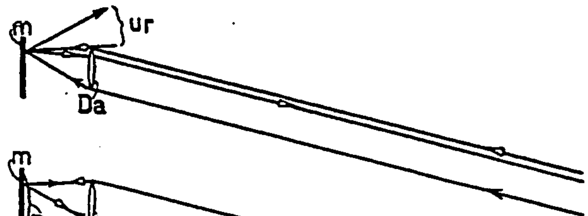

FIG_36_

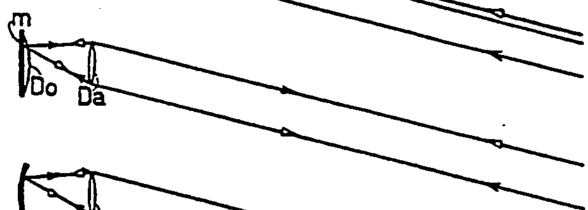

FIG_37_

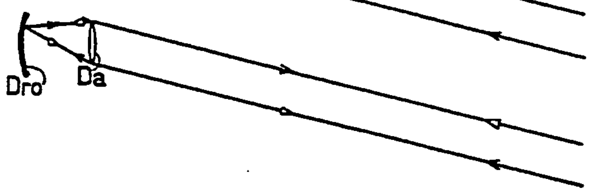

FIG_38_

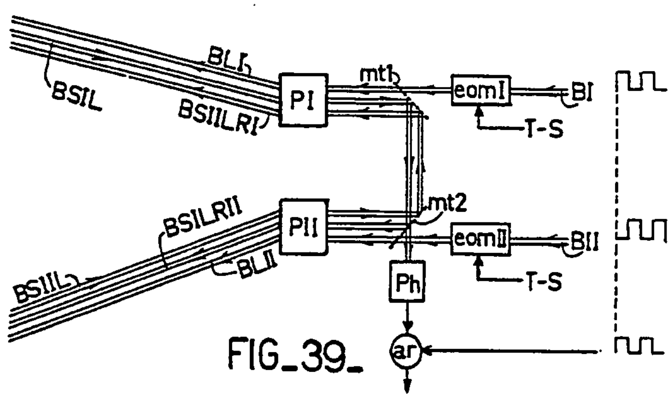

FIG_39_

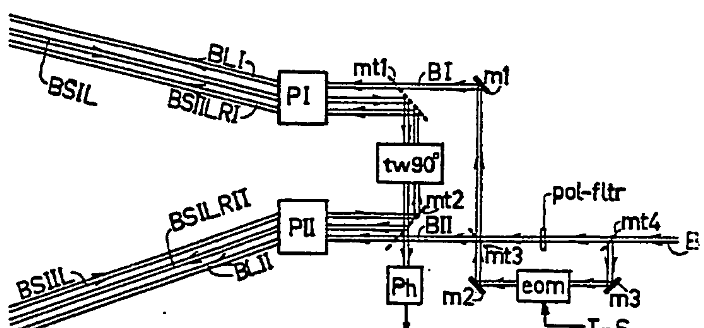

FIG_40_